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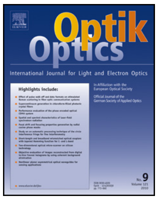

Original research article

Simultaneous dual-parameter measurement based on dual-channel surface plasmon resonance in photonic crystal fiber

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A PCF-based dual-parameter sensor is investigated based on dual-channel Surface Plasmon Resonance (SPR). The sensing property can be manipulated just by optimizing the cross-section and selectively infiltrating the cladding air-holes with magnetic fluids (MF). Based on the dependence of the MF refractive index (RI) on temperature and magnetic field, the sensitivity of the spectral response to these two parameters can be characterized by finite element method (FEM). The proposed structure provides a new dual-parameter measurement method to eliminate the cross sensing effect.

1. Introduction

Photonic crystal fibers (PCF), with the unique arrangement structure of the cladding air holes, have presented an attractive platform for optical sensing such as temperature, pressure or refractive index due to their design flexibility [1–3]. The sensing characteristics of PCF have been extended by filling the cladding air-holes with different materials [4–7]. Among these PCF-based designs, SPR technology by the use of coated metallic layer [8–10] or nanowires [11–13] has attracted immense attention due to its special sensing mechanism. The difference is that, the metal film is suitable for larger air-holes and metal nanowires can be used for smaller air-holes due to the limitation of processing technology. With a strong coupling between the core mode and the surface plasmon polaritons (SPP) mode, a high sensitivity for different measurements can be achieved when the phase matching condition is satisfied. It's worth mentioning that the sensing characteristics can be characterized by analyzing the confinement losses spectra. The combined use of two sensing laid a theoretical foundation for future research on PCF-based dual-parameter sensors. An additional degree of freedom would be added to explore the simultaneous measurement techniques.

Because of the tunable RI characteristic of MF materials, which is dependent on both the external temperature and applied magnetic field [14], MF materials can be inserted into the cladding air-holes of the PCF to measure the temperature and magnetic field simultaneously. The basis for measuring these two parameters is to have a differential sensitivity to each sensing channel. We present and demonstrate a feasible configuration just based on a segment of designed PCF which can be easily realized. The SPR effect is studied by finite element method (FEM), and simulation of the PCF-based sensor's

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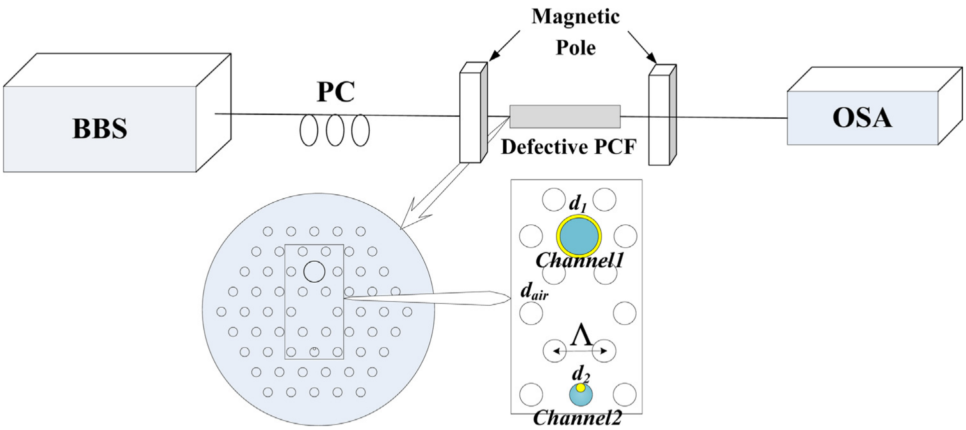

Fig. 1. PCF demodulation principle diagram and the cross section of PCF.

Table 1
Values of the optimized parameters

d_1	d_2	d_{air}	d_{gold1}	d_{gold2}	Δ
2.6 um	1.1 um	1.1 um	45 nm	300 nm	2.8

performance is carried out through dual-wavelength matrix method. The method provides a possibility to realize a PCF-based dual-parameter sensor without the cross-sensitivity effect between the temperature and magnetic field.

2. Model and method

The theoretical model is established as Fig. 1, and the perfectly matched layers (PML) boundary condition [15] is used to calculate the effective indices of electromagnetic mode in complex domain. The resonance modes are usually divided into horizontal polarization state (*x*-polarized) and vertical polarization state (*y*-polarized). For definiteness and without loss of generality, we select *y*-polarized state for the research in following discussions. As is shown in Fig. 1, the experiment setup starts with an optical broadband source (BBS), and the transmitted light enters the PCF via a polarization controller (PC). Then the spectral response can be observed by using an optical spectrum analyzer (OSA) with a 0.1 nm resolution. Two different detect channels are introduced in the cross-section of the PCF. Both of two channels are filled with same MF material, but the difference is that the Channel-1 is coated with a gold layer whose thickness is d_{gold1} but the Channel-2 is filled with gold nanowire d_{gold2}. The diameter of two channels are defined as d_1 and d_2, respectively. The photonic lattice period is selected as Λ and the adjacent air-holes with a diameter d_{air}. The structural parameters used in this paper are presented in Table 1.

SPR effect generally occurs when the phase-matching condition is satisfied [16], and the confinement loss of a core-guided mode can be calculated by Eq. (1). The imaginary part of the complex effective refractive index n_{eff} should be calculated at first.

$$\alpha(dB/cm) = \frac{40\pi Im(n_{eff})}{\lambda \ln(10)} \times 10^4 \tag{1}$$

The background material is pure silica, whose material dispersion is determined by the Sellimeiers equation as is shown in Eq. (2) [17]. The dispersion of gold is described by the Drude–Lorentz model [18] as is shown in Eq. (3). Here, ε_{Au} is the permittivity of the metal, $\varepsilon_\infty = 9.75$is the permittivity in infinite frequency, $\omega_p = 1.36 \times 10^{16} rad/s$and $\omega_\tau = 1.45 \times 10^{14} rad/s$ are the plasma frequency and collision frequency.

$$n^2 = 1 + \frac{0.6961663\lambda^2}{\lambda^2\text{-}(0.0684043)^2} + \frac{0.4079426\lambda^2}{\lambda^2\text{-}(0.1162414)^2} + \frac{0.8974794\lambda^2}{\lambda^2\text{-}(9.896161)^2} \tag{2}$$

$$\varepsilon_{Au}(\omega) = \varepsilon_\infty\text{-}\frac{\omega_p^2}{\omega^2 + i\omega\omega_\tau} \tag{3}$$

The thickness of the metal layer and the radius of gold nanowire are key factors influencing the half-width and amplitude of the resonant peak, and their effects on the sensing performance are systemically investigated. Fig. 2(a) shows the loss spectra of the core-guided mode for different thicknesses of the gold layer. The resonance wavelength moves towards longer wavelength and the resonance peak decreases as the increase of the thickness from 40 nm to 50 nm when the temperature is 20 °C. Fig. 2(b) shows the loss spectra of the core-guided mode for different radius of the gold nanowire which range from 130 nm to 150 nm. In order to eliminate the problem of cross-sensitive for fundamental mode, we choose the thickness of the metal layerd_{gold1} = 45 nm and radius of the gold nanowiredgold2 = 300 nm.